A Study of Copper Dissolution in Pb-free Solder Fountain Systems

The Product Realization Company

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Presented at SMTAI
September 26, 2006

Outline

- Problem definition
  - Greater Cu dissolution expected for processes where molten solder contacts Cu
    - – Data from Pb-free HASL and early wave studies
    - – High Sn and higher temperatures
  - Needed objective data comparing
    - – Alloy differences
    - – Process variables, e.g. temperature
- Methodology: two-pronged approach
  - Wire dissolution: more analytical, controlled approach
  - Trace Dissolution: link to performance on real geometries
- Results
  - Wire Dissolution
  - Trace Dissolution
- Conclusions

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Methodology: Wire dissolution

- Tensioning tool provided uniform force
  - Force set by distance
  - Measured before and after testing
  - Output was time to break
- Three wire diameters used
  - 6-mil, 9.5-mil, 14-mil
  - Provided opportunity for better modeling
- Ten samples per cell
  - Best compromise between time and resolution given expected scatter
- Three temperatures: 235, 250, 265°C

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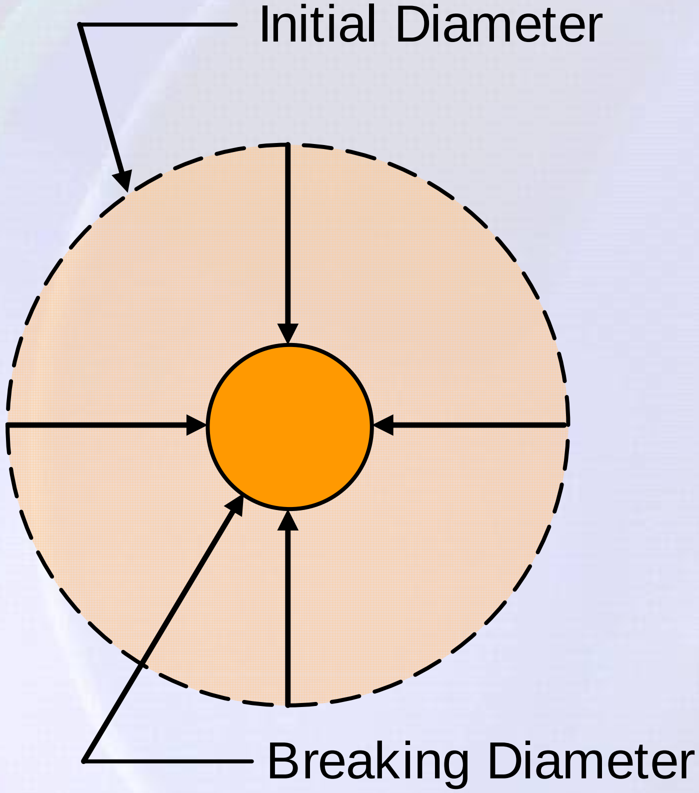
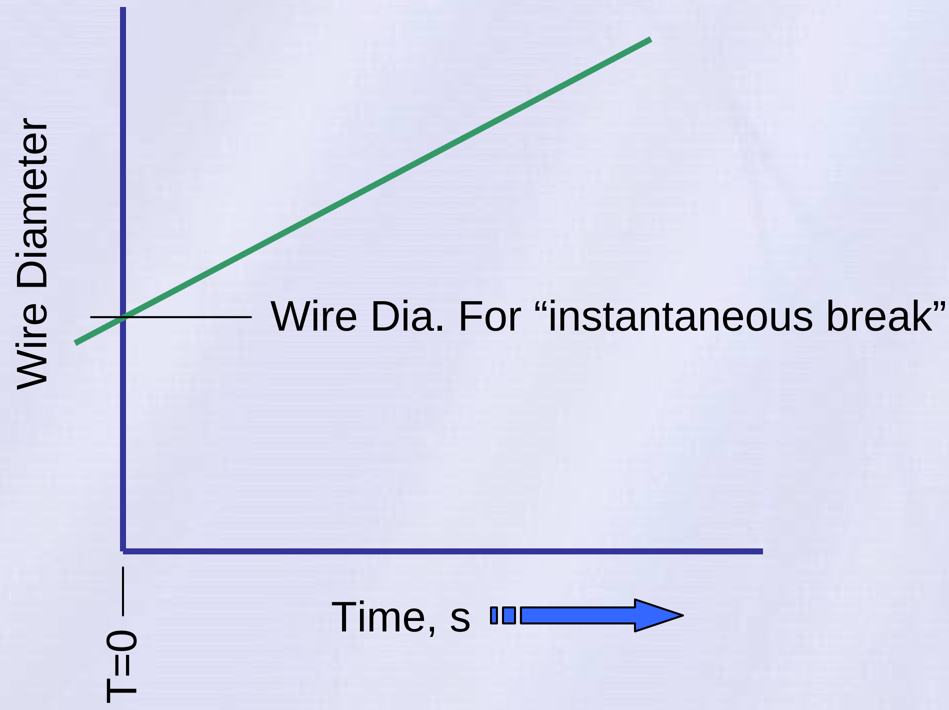
Model: Wire Dissolution



- Assume uniform and constant etch rate
  - Wire remains round
- Break diameter estimate from materials properties
  - Initial estimate, 3.9 mils
  - Refined based on data
- Rate = ½ $(D_i - D_b) / t$

Wire Dissolution: Break Diameter

- Regression on wire dia. vs. immersion time
- Y-intercept estimates true break diameter
  - Average = 4.34 mils (250°C and 265°C data)
- Assumes uniform etch rate (wire remains round)



Wire Dissolution Raw Data

	SAC-305			4-Part			Doped SnCu			SnPb		
Wire Dia.:	**0.006"**	**0.095"**	**0.014"**	**0.006"**	**0.095"**	**0.014"**	**0.006"**	**0.095"**	**0.014"**	**0.006"**	**0.095"**	**0.014"**
250C:	7.78	22.10	41.59	20.00	61.93	126.22	22.12	59.32	113.66			
	7.50	24.94	47.22	18.50	50.91	137.91	21.25	53.50	127.91			
	7.62	24.25	40.72	26.06	56.00	127.72	23.79	51.00	98.28			
	7.66	22.21	43.22	21.56	56.47	119.00	20.47	48.59	115.78			
	7.41	22.78	43.16	25.15	59.16	130.85	18.60	55.88	154.31			
	9.78	22.41	45.28	19.69	61.50	91.91	23.03	50.29	118.37			
	7.28	26.46	42.81	24.85	56.18	111.15	16.37	50.47	104.63			
	7.47	23.34	38.97	21.41	52.50	105.93	18.25	49.15	119.38			
	10.72	26.87	40.56	22.41	56.12	148.91	17.82	62.97	98.66			
	7.47	23.47	41.31	21.85	70.28	134.46	20.84	72.62	104.68			
Average:	8.069	23.883	42.484	22.148	58.105	123.41	20.254	55.379	115.57			
Std Dev.	1.179	1.721	2.420	2.508	5.512	16.773	2.423	7.661	16.674			
CV:	14.6%	7.2%	5.7%	11.3%	9.5%	13.6%	12.0%	13.8%	14.4%			

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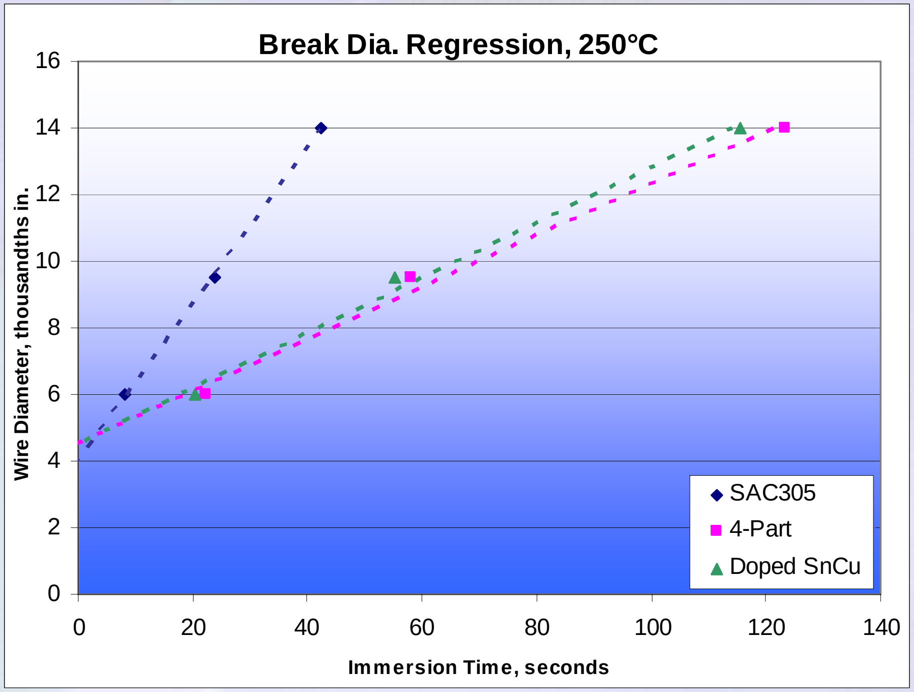
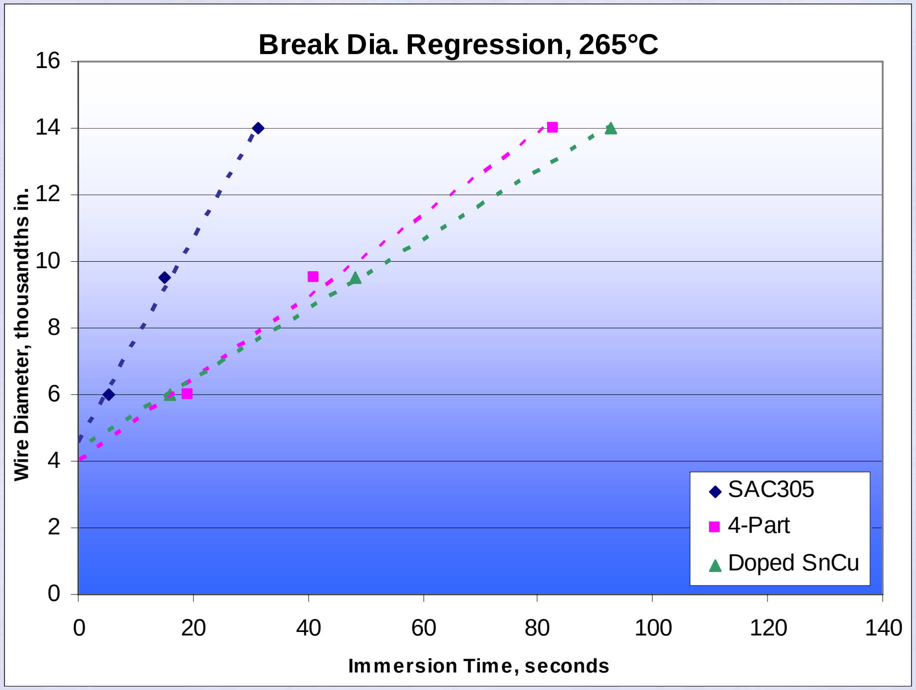
Wire Break Regression





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Wire Break Regression

- Average break diameter of 4.34 mils based on 250°C and 265°C data
  - The 235°C data were not used due to proximity to melt point
- Correlation to within +11% of value predicted using R.T. material properties
  - Break diameter should be larger due to:
    - Drop in strength due to increased temperature
    - Local defects should trigger earlier crack initiation

Wire Dissolution: ANOVA

ANOVA: Rate versus Alloy, Diameter

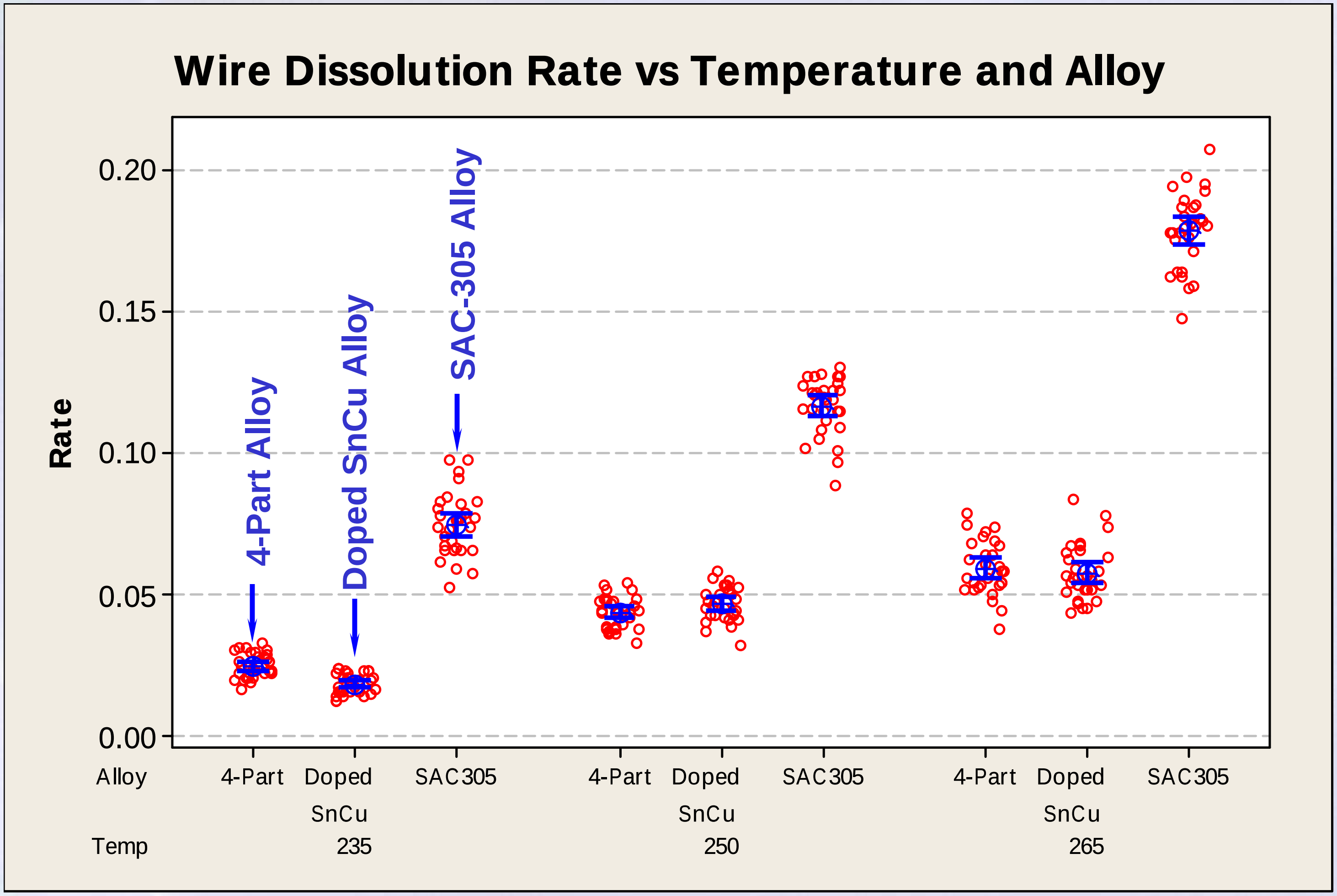
Analysis of Variance for Rate_434

Source	DF	SS	MS	F	P
Alloy	2	0.352814	0.176407	3354.21	0.000
Temp	2	0.140281	0.070141	1333.66	0.000
Diameter	2	0.001445	0.000722	13.73	0.000
Alloy*Temp	4	0.043288	0.010822	205.77	0.000
Alloy*Diameter	4	0.001030	0.000257	4.89	0.001
Temp*Diameter	4	0.001066	0.000266	5.07	0.001
Error	251	0.013201	0.000053		
Total	269	0.553124			

Wire Dissolution: ANOVA

- Alloy and Temperature by far largest contributors to variance
  - Alloy*Temp interaction also large, but nearly 1 order of magnitude smaller
- Wire Diameter effect very small by comparison, though statistically significant
  - Interactions with wire diameter also small
- Choice of 10 samples per cell was more than sufficient to resolve main effects

Wire Dissolution: Means Plots



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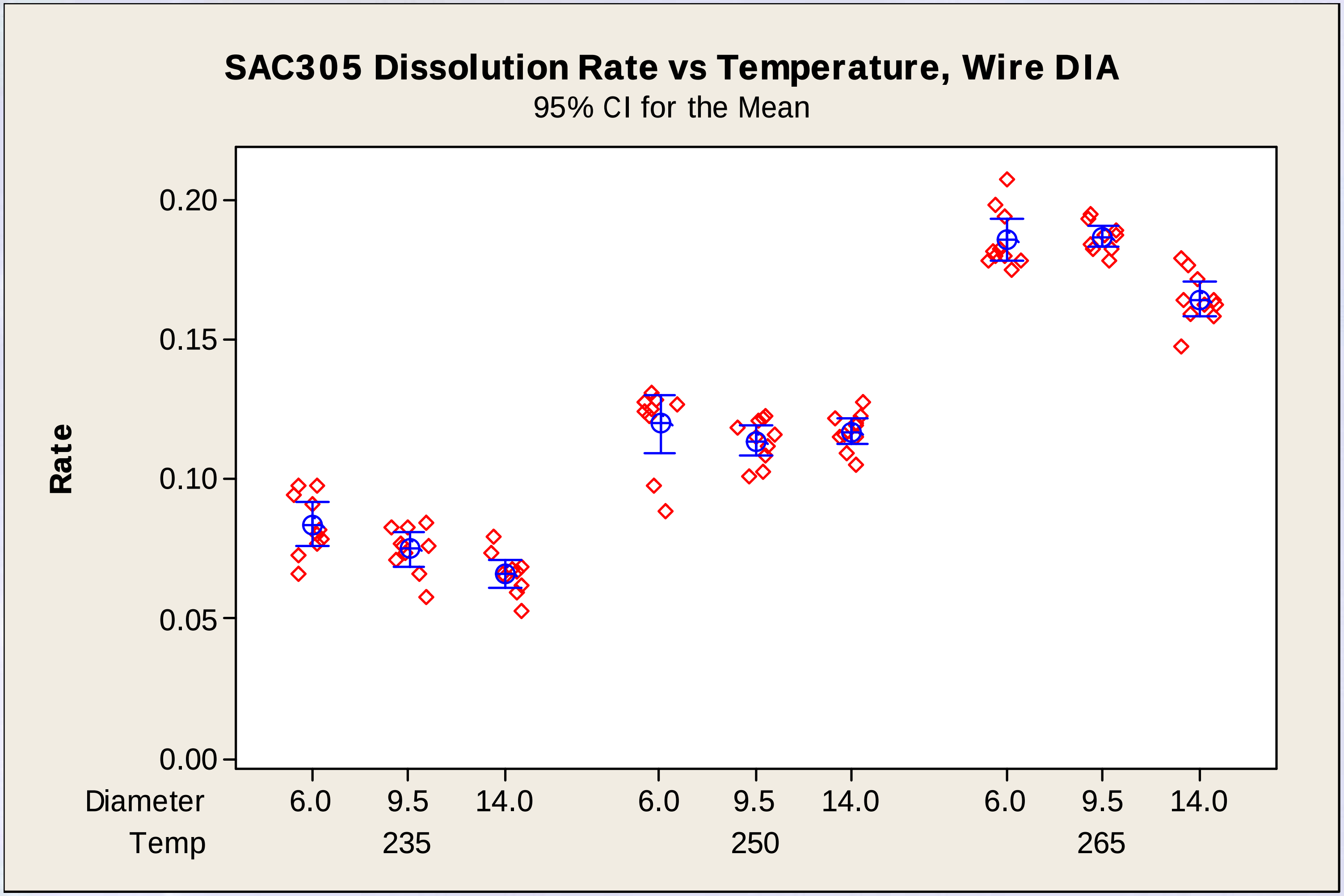
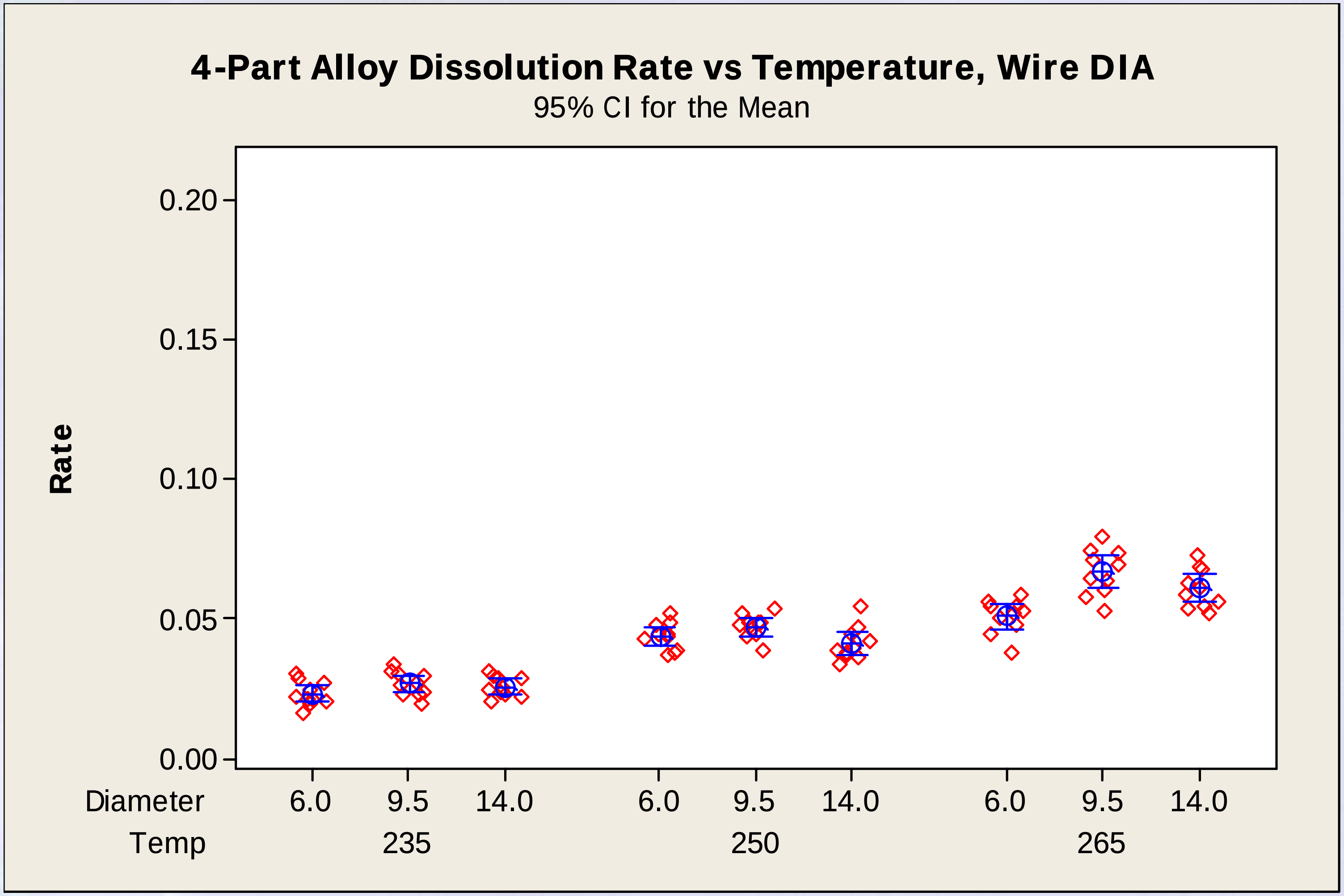
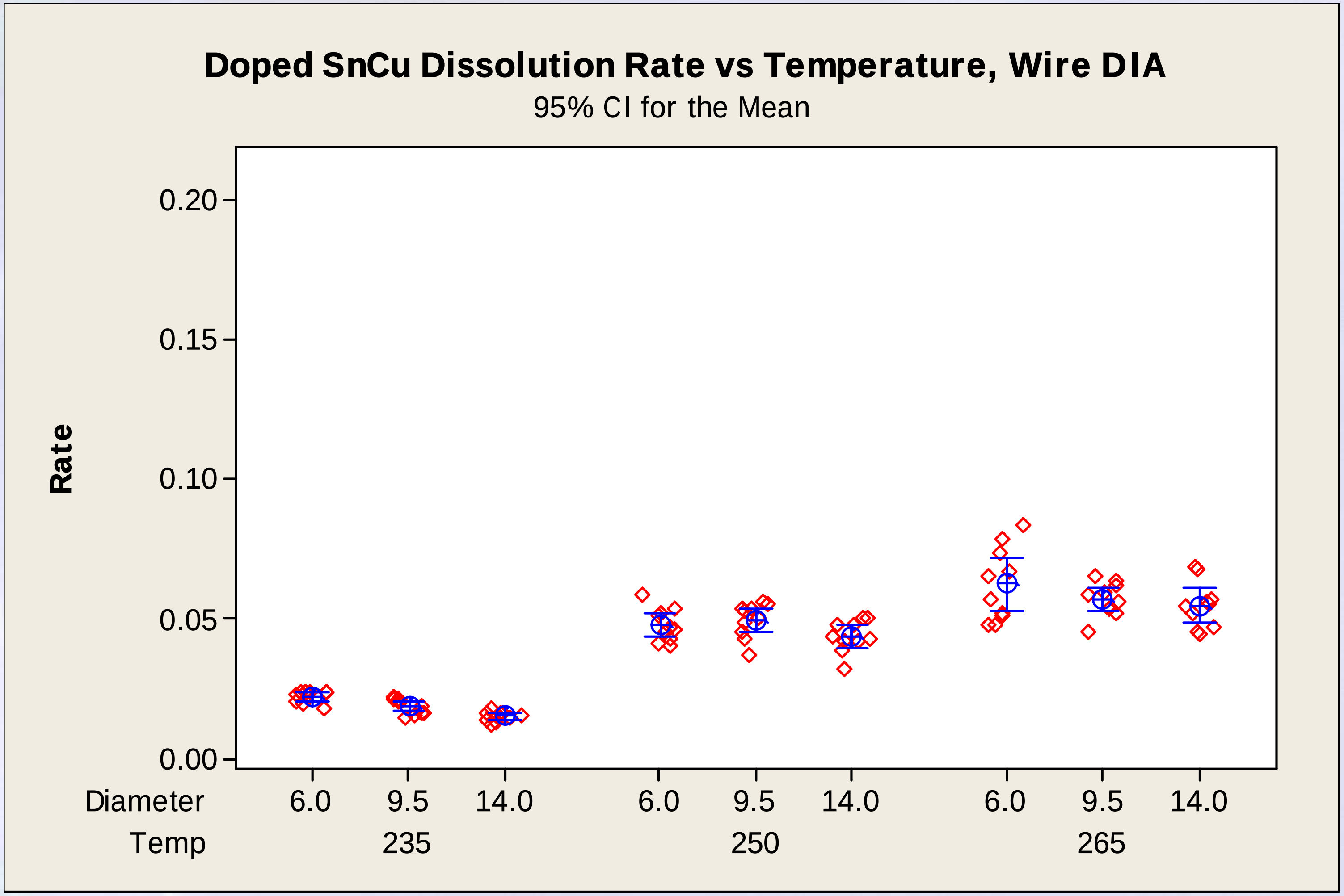
Wire Dissolution: Means Plots



Wire Dissolution: Means Plots



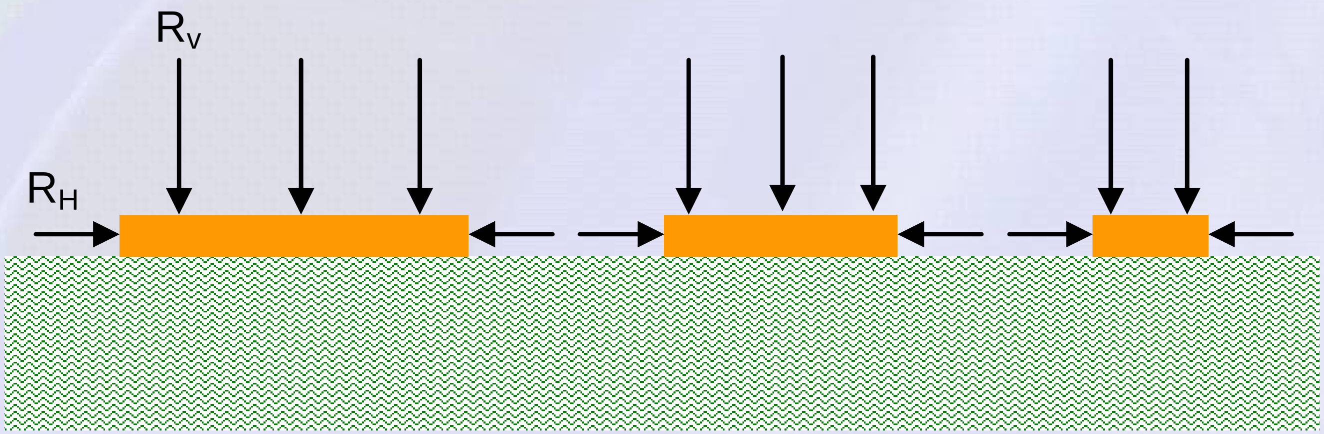
Wire Dissolution: Means Plots



Wire Dissolution Rates: Discussion

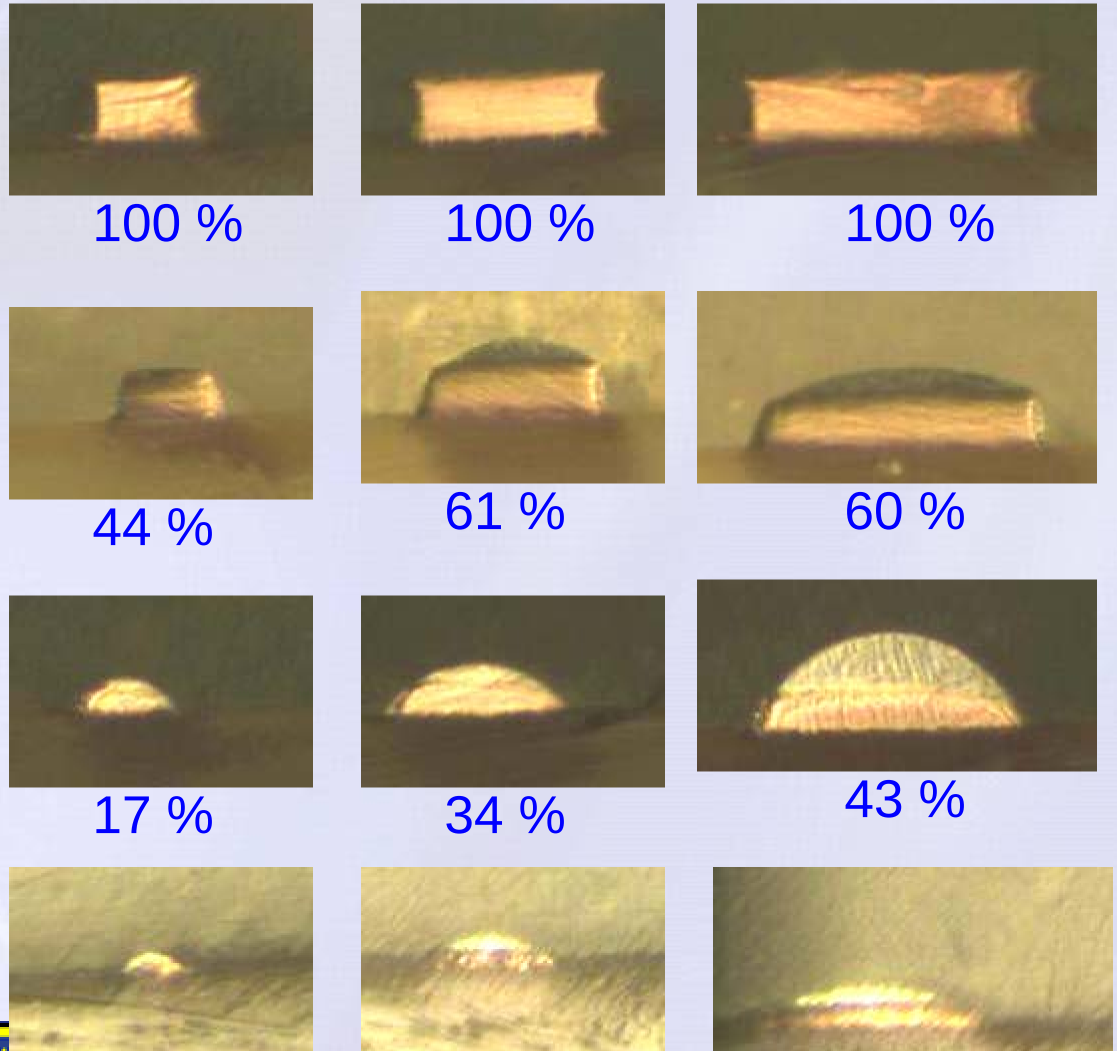
- Dissolution rates for doped SnCu and 4-Part alloys were very similar for 250° and 265° conditions
- Dissolution rates for SAC305 were approx. 2.5 times higher than SnCu and the 4-Part alloy, at like temperatures
- Dissolution rates approaching 0.2 mils/s were recorded
  - Could dissolve typical 2-mil-thick trace in 10s!
  - Wire dissolution was expected to overstate rates to some unknown degree

Trace Dissolution Model



- Assume $R_V > R_H$
  - R_H limited by stagnation near PWB surface?
- Assumed constant rates
  - Corners a known problem area, model would not accurately reflect these
- Model did not take wetting time into account
  - Would make a difference for PTH
  - Also complicated by stagnation in PTH

Trace Dissolution, SAC305 @ 265°C



	5 mil Trace	10 mil Trace	15 mil Trace
Initial	100 %	100 %	100 %
10 sec.	44 %	61 %	60 %
20 sec.	17 %	34 %	43 %
30 sec.	4 %	21 %	19 %

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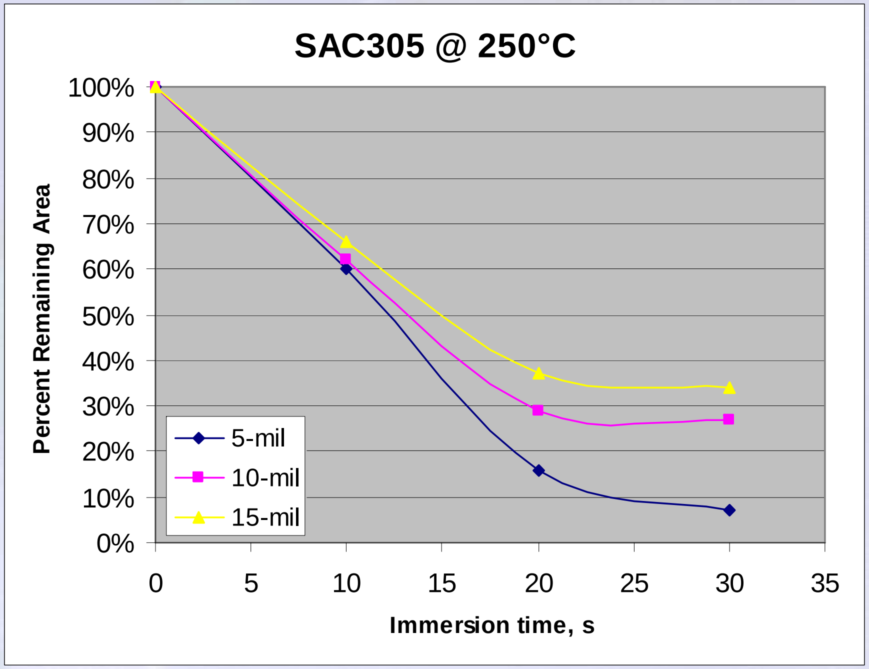
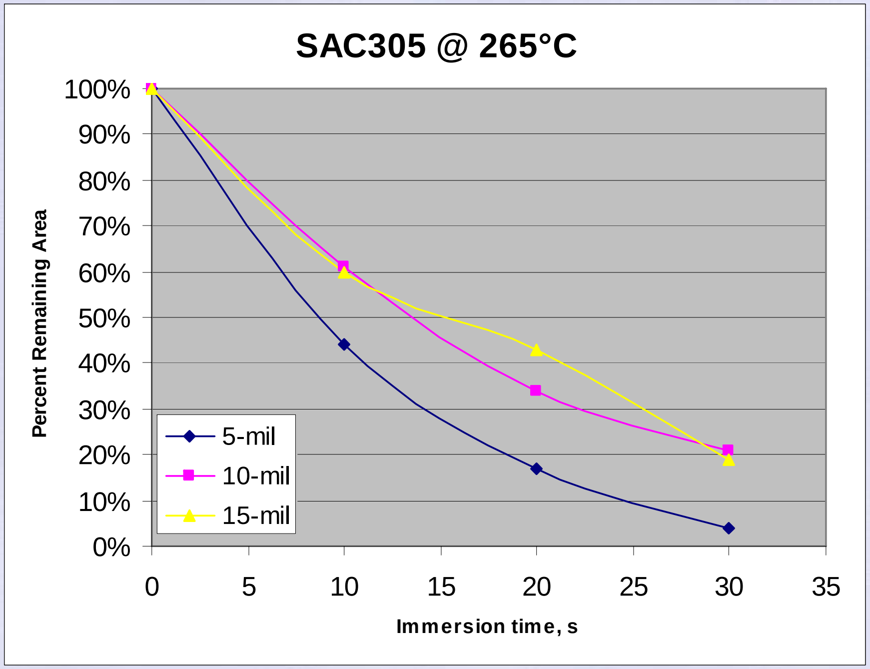
Trace Dissolution, SAC305



Initial rate of 0.067 mils/ second



Initial rate of 0.085 mils/ second

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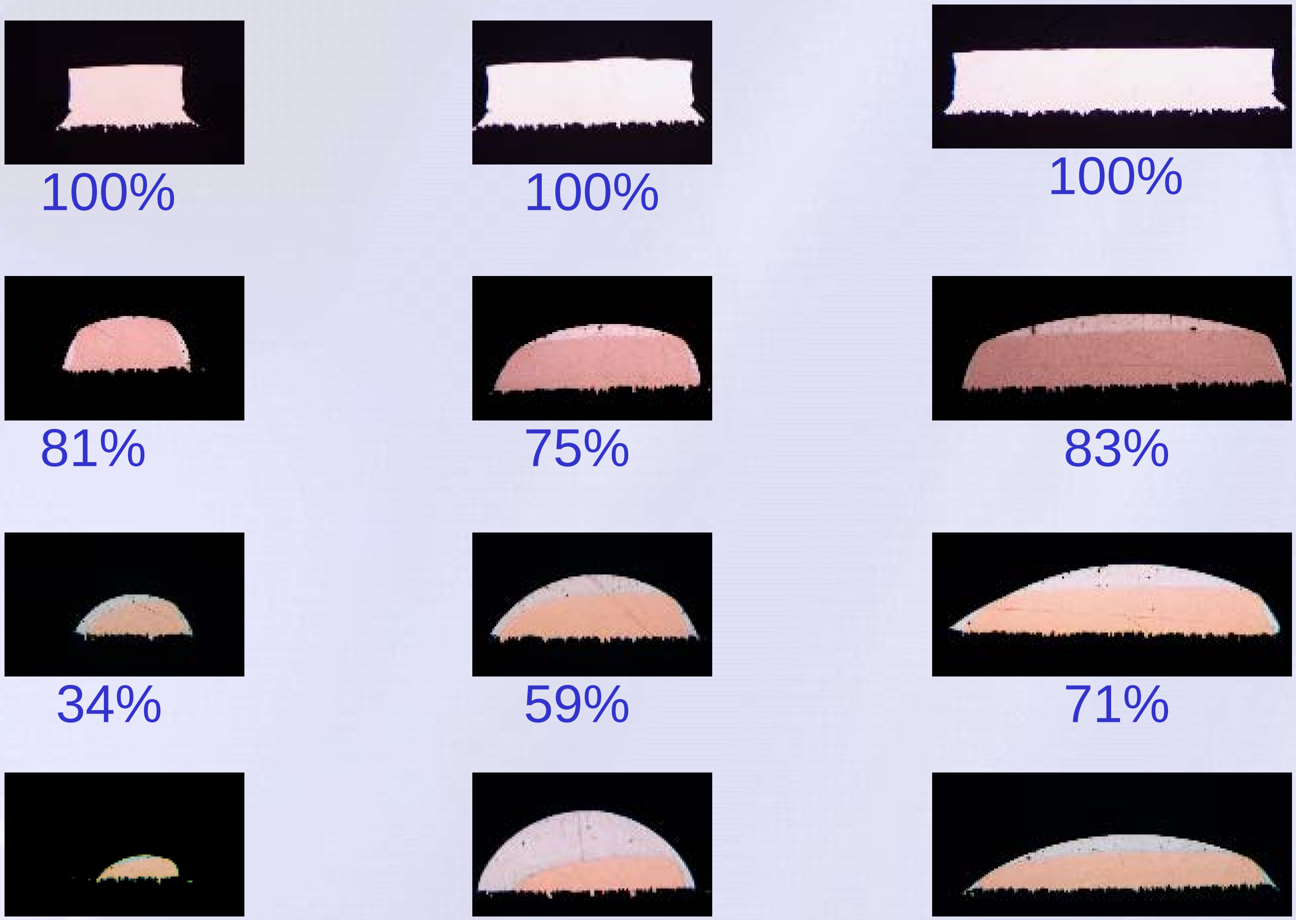
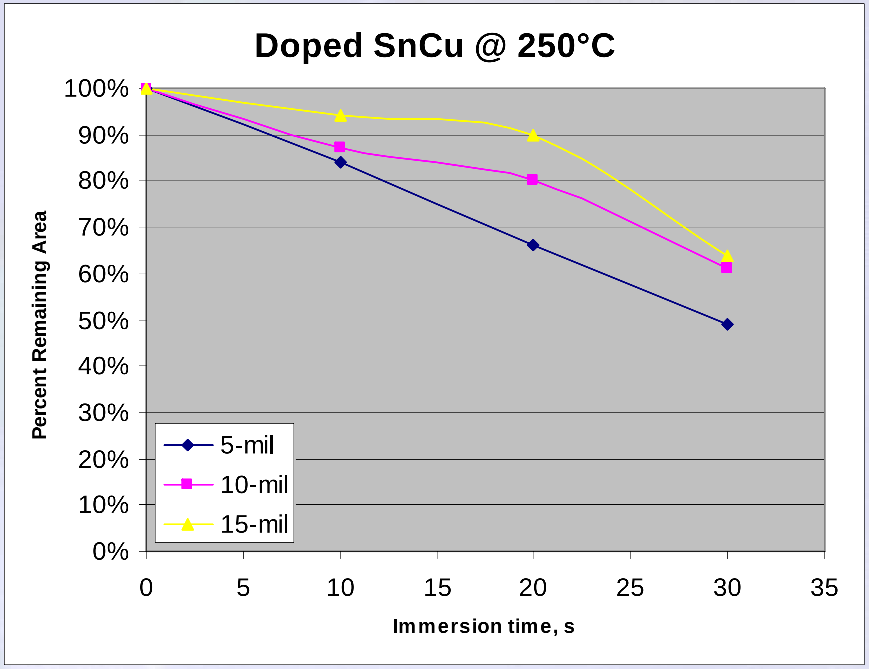
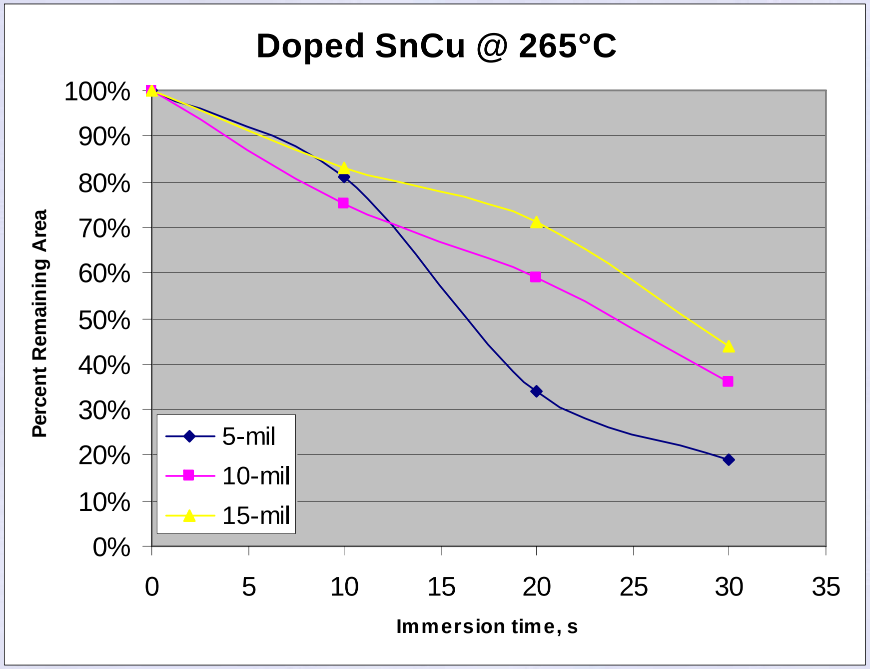
Trace Dissolution, Doped SnCu @ 265°C



	5 mil Trace	10 mil Trace	15 mil Trace
Initial	100%	100%	100%
10 sec.	81%	75%	83%
20 sec.	34%	59%	71%
30 sec.	19%	36%	44%

Trace Dissolution, Doped SnCu





Initial Rate of 0.030 mils/s

Initial Rate of 0.043 mils/s

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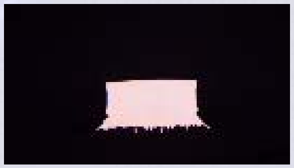
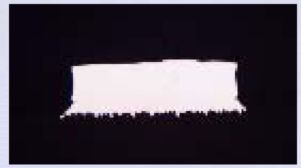
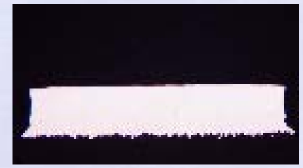
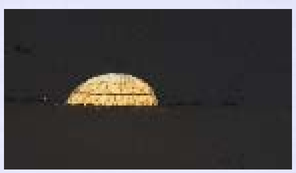
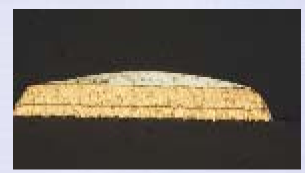
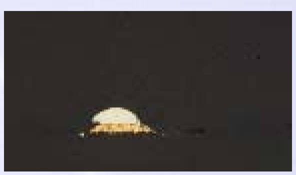
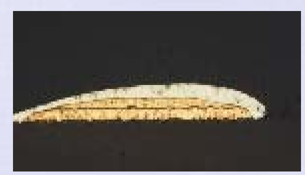
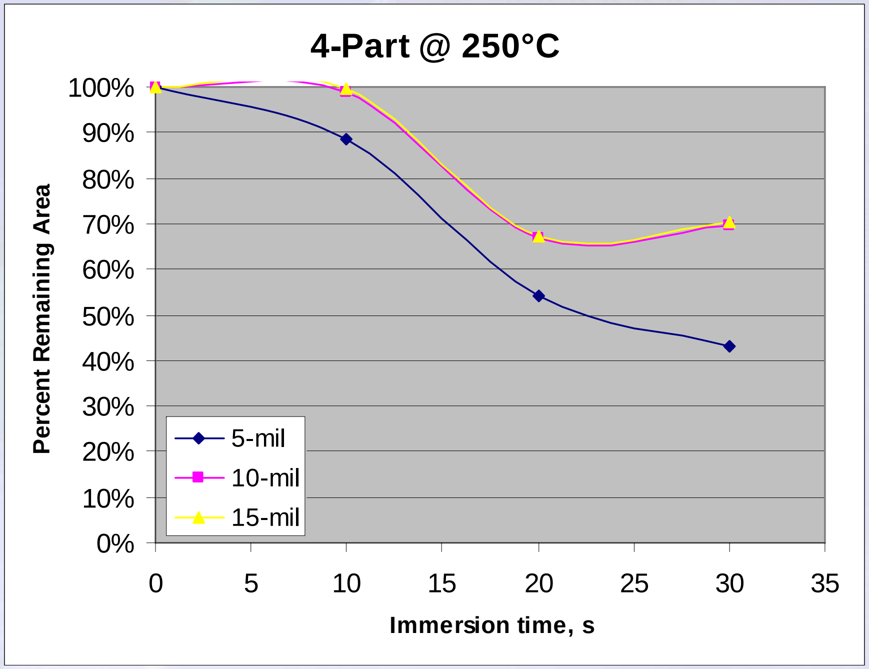
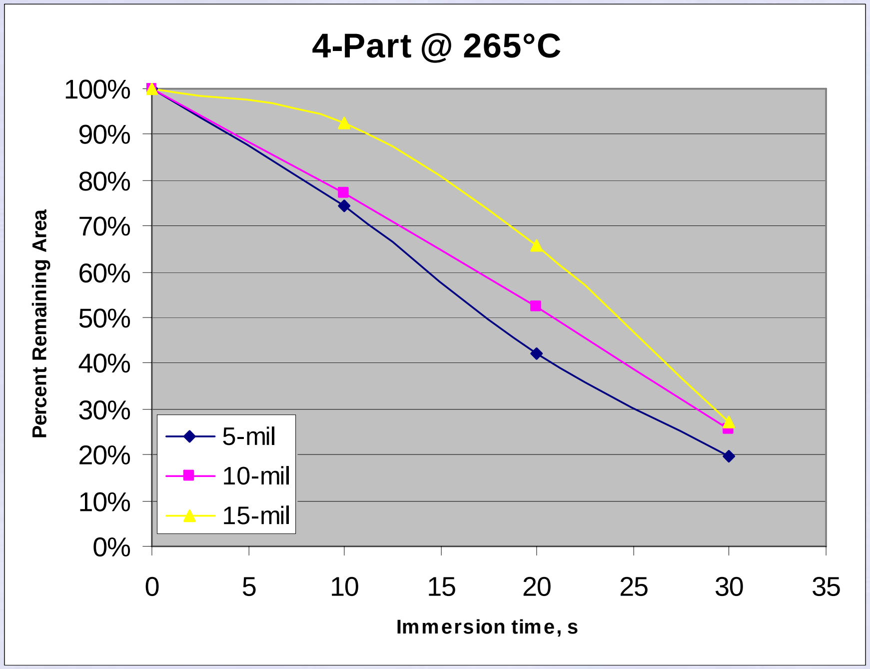
Trace Dissolution, 4-Part @ 265°C

	5 mil Trace	10 mil Trace	15 mil Trace
Initial	 100%	 100%	 100%
10 sec.	 75%	 78%	 93%
20 sec.	 42%	 52%	 66%
30 sec.	 20%	 25%	 27%

Trace Dissolution, 4-Part



Initial Rate of 0.035 mils/s



Initial Rate of 0.045 mils/s

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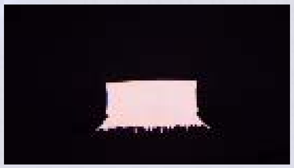
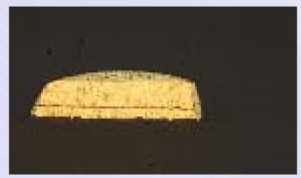
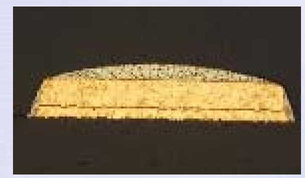
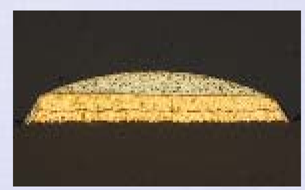
Trace Dissolution, SnPb @ 265°C

	5 mil Trace	10 mil Trace	15 mil Trace
Initial	 100%	 100%	 100%
10 sec.	 69%	 72%	 72%
20 sec.	 50%	 52%	 65%
30 sec.	 44%	 39%	 54%

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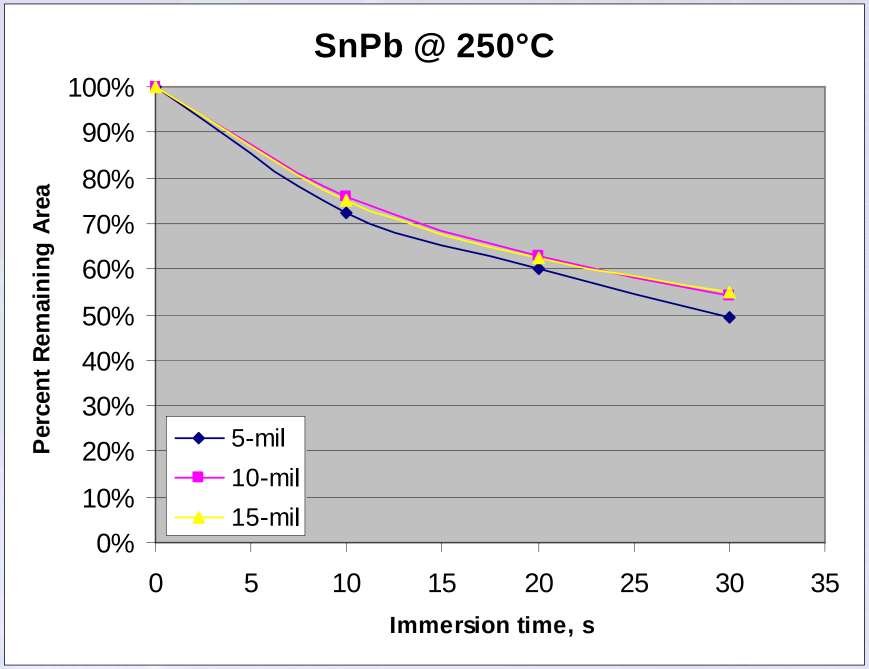
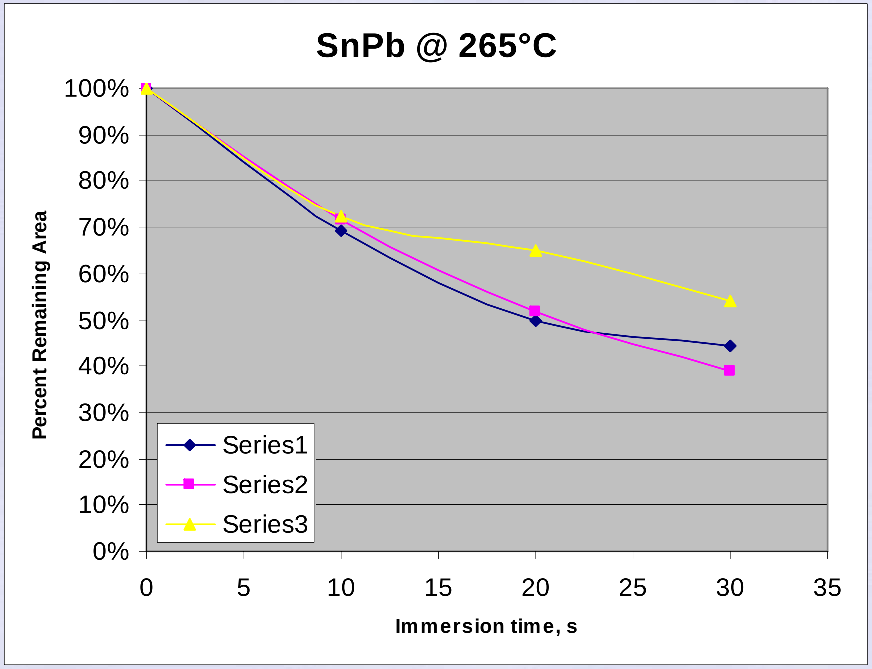
Trace Dissolution, SnPb





Initial Rate of 0.035 mils/s

Initial Rate of 0.040 mils/s

Trace Dissolution: Discussion

- Trace dissolution rates were lower than for wire dissolution at like conditions
  - Rates were approx. 65-70% of wire dissolution
  - Much more scatter in trace dissolution data
- Trace dissolution data much more difficult to collect, and more prone to process and analyst error
  - Trace dissolution directly relates to PWBs, whereas wire dissolution does not

Conclusions

- The 4-part alloy and doped SnCu alloys were equivalent in performance with regard to dissolution rate of Cu.
- The SAC-305 had much higher dissolution rates, approx. 2.5x higher in the range of 250°C to 265°C
- At 250°C, both the 4-part alloy and the doped SnCu alloy performed equivalently to SnPb in the trace dissolution test.
- At 265°C, the dissolution rates for all Pb-free alloys were greater than for SnPb
    - Rates in the first 20s were similar to SnPb for 4-Part and Doped SNCu alloys.

Conclusions, Cont'd.

The Good News:

- A Pb-free process is feasible
- A SAC-family alloy is a possibility
- Dissolution rates similar to SnPb can be achieved

The Bad News:

- Process window will be narrower
- Alloy will not likely be the same as reflow or wave
- Equipment and flux requirements may need review to meet process window